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Three-Dimensional Distribution of the Magnetic Field and the Flux in Locally Magnetized Two-Layer Ferromagnetic Objects

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Abstract. Numerical simulation of the spatial distribution of the magnetic field and the flux in two-layer objects is executed. The possibility of measuring the depth of a highly coercive layer on a soft magnetic core by the magnetic field measured on the surface of the object in the interpolar space of a U-shaped electromagnet is theoretically and experimentally shown.

INTRODUCTION

There are several widely used methods of face hardening of steel articles in modern machine-building [1, 2]. Generally the quality of face hardening is evaluated by the hardness and depth of a hardened layer. In some cases it is necessary to determine the hardness of an unhardened core [3].

Due to the fact that destructive methods are complex and labor-consuming and that they cannot be used to test all articles, the determination of the hardness and depth of a hardened layer by nondestructive methods is relevant to the present day. There are studies on the determination of the depth of a hardened layer by ultrasonic inspection [4]; however, coercimetric methods for inspecting a hardened layer have a more prevalent practical application [3, 5–10].

There are two attached transducers with different sizes and, accordingly, different magnetization depths (or volumes) that are used in coercimetric techniques [3, 5–8]. One can evaluate the magnitude of the coercive force, averaged over the entire magnetized volume, by demagnetization current in the coils of an attached electromagnet. Measurements using each detector must be conducted at the same point of the tested object. First, in order to determine the hardness of a hardened layer, it is necessary to measure the relative value of the coercive force by a transducer. This transducer should have a small magnetization depth, which must be smaller than the minimum required thickness of the hardened layer. Then, measurements must be made by a transducer with a large magnetization depth. Using the results of both measurements, we can evaluate the depth of the hardened layer. This technique is very time- and labor-consuming. Its correct application is possible only when the depth and magnetic properties of the layer are identical in the volume, which is magnetized by the biggest electromagnet (this is not always carried out in practice). Besides, the transducer with a lesser magnetization depth (namely, with a small cross section of the poles and a small interpolar distance) is very sensitive to the quality of the surface being tested and to gaps in the “electromagnet-object” circuit [8].

To develop new and more advanced techniques of face hardening, magnetic testing requires studying the three-dimensional distribution of magnetic flux at a locally magnetized two-layer ferromagnetic object, and this is the aim of this paper.

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SPECIMENS AND RESEARCH METHODS

The research was made by numerical simulation using the ANSYS program [11]. Methods for making the calculation was discussed in detail in [12, 13].

The model of a massive two-layer object locally magnetized by a U-shaped electromagnet is graphically presented in Fig. 1. The magnetic properties of the upper layer, which is imitating face hardening, are as follows: H_c=35 A/cm, μ=40. The thickness of the hardened layer *D* is varied from 0 to 15 mm.

The properties of the low layer, which is imitating the core, are as follows: H_c=5 A/cm, μ=200. The object to be tested has the following dimensions: a height of 230 mm, a width of 300 mm, and a two-layer thickness of 56 mm. The attached electromagnet is 100 mm in height, with the pole dimensions 15×28 mm. The magnetomotive force is 1800 ampere-turns.

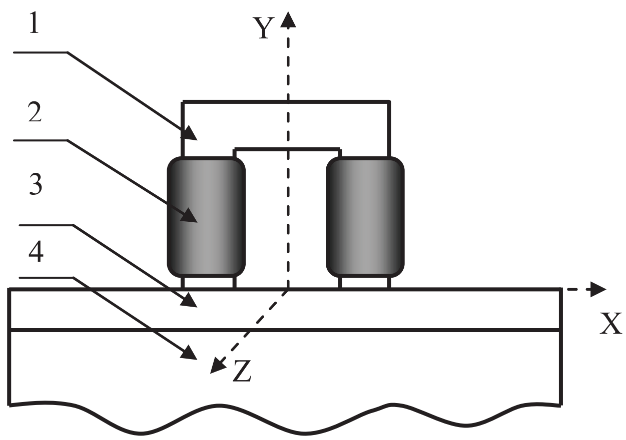


FIGURE 1. The calculation model: 1 – magnetic circuit; 2 – the magnetizing coil; 3 – the hardened layer; 4 – the object core

RESULTS AND DISCUSSION

Magnetic flux and field distributions in the neutral plane of the electromagnet above the surface and inside the magnetized object are represented in Fig. 2 for various values of the hardened depth. The average magnetic flux density in the hardened layer remains unchanged as *D* increases from 0 to 15 mm (Fig. 2a). However, when $D \geq 5$ mm, magnetic flux density becomes unalike at different depths of this layer (it decreases from the upper bound to the lower one). This difference increases with the layer thickness *D*. When *D*=10 mm, the value of *B* on the surface differs about 2 times from that at the lower bound of the hardened layer.

It is obvious from Fig. 2b that, at a constant value of the magnetomotive force of the electromagnet, the field on the object surface in the center of the interpolar space (point A) grows monotonically with the thickness of the hardened layer. The corresponding dependence is shown in Fig. 3a.

As to the calculations, the field H_A grows practically linearly on the object surface as *D* increases from 2 mm to 15 mm, increasing more than 2 times. Thus, the field H_A is a potential parameter to test the hardened layer depth even when *D* exceeds the thickness of the electromagnet pole. However, the measurement of the magnetization curve parameters, which include H_A, is impeded in practice as a result of the impossibility of the high-quality demagnetization of large-volume articles and complex-shaped articles.

To define a more appropriate inspection parameter, field intensity H_p is measured by a SIMTEST device [14, 15]. This field is achieved in the center of the interpolar space (point A) on the surface of two-layer objects after they are magnetized by a U-shaped electromagnet with subsequent magnetization reversal along the descending hysteresis loop branch until reaching a fixed magnetic flux value [16]. The hardened layer is consists of polished plates with different thicknesses, the material of these plates being hardened steel 62S2. The core is a polished plate sized 100×170×34 mm and made of annealed steel 3. The obtained experimental data are represented in Fig. 3b.

As it follows from the obtained results, the field H_p correlates with the calculated field H_A; however, H_p can be easily measured with existing devices unlike H_A [14, 15]. Thus, it is possible to test the depth of the hardened layer by the magnetic field value measured on the surface of a locally magnetized object.

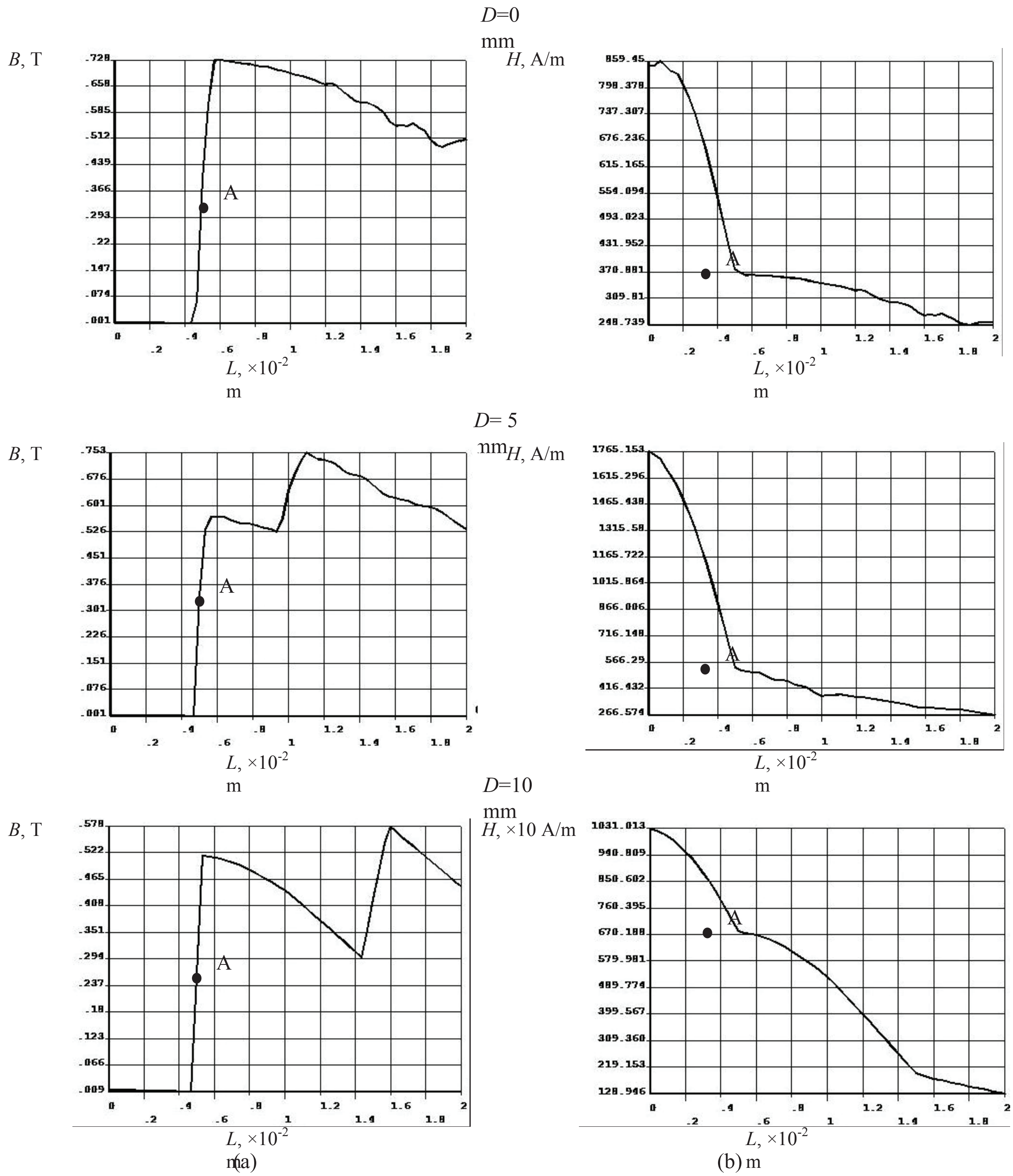
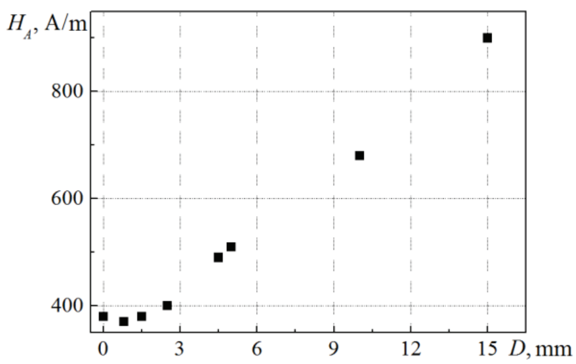


FIGURE 2. The distribution magnetic flux (a) and magnetic field intensity (b) in the neutral electromagnet plane above (to the left of point A) and inside the surface (to the right of point A) of magnetized objects with different hardened depths *D*



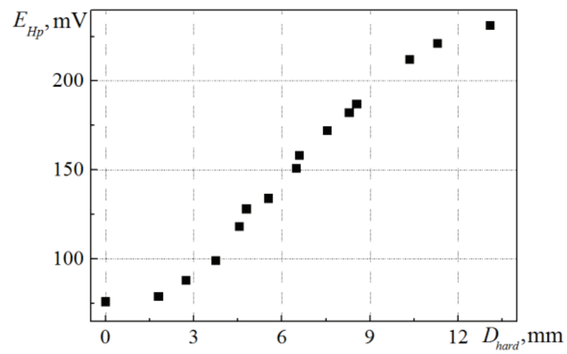


FIGURE 3. The calculated dependence of magnetic field intensity in the interpolar space of the electromagnet on the two-layer object surface on the hardened layer thickness at a fixed magnetomotive force (a) and the dependence of the relative value of magnetic field intensity on the two-layer object surface after magnetization reversal along the descending hysteresis loop branch until reaching a fixed magnetic flux value on the hardened layer thickness D_{hard} (b)

CONCLUSION

It has been established experimentally and by numerical modeling that it is possible to determine hardened layer depth on the surface of a soft-magnetic core by the magnetic field value on a locally magnetized object surface. Comparing with the coercimetric technique [3], the range of the thickness to be tested can exceed the thickness of the attached electromagnet.

The development of techniques and devices that would employ express measurement of necessary magnetic test parameters using a single transducer for selective detection of hardened layer parameters would be very useful.

The reference section will follow the “Acknowledgment” section. References should be numbered using Arabic numerals followed by a period (.) as shown below, and should follow the format in the below examples.

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